DEVELOPMENT OF FIRST PRODUCTION FLAW DETECTING SYSTEM FOR ON-DEMAND REPAIR OF LARGE-SCALE CIRCUIT

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Abstract:

In order to realize efficient high-mix low-volume production, improvement of yield rate by reducing production flaw is important technique. Manufacturing of touch panel display with large scale wiring board is a typical example of the high-mix low-volume production. AIST has proposed Laser assisted Ink-Jet printing (LIJ) technology, which can repair the flaw of circuit with silver nanoparticle ink. To establish in-process repairing system for touch panel display, a first production flaw detecting system is demanded with combining to the LIJ technology. Therefore, the aim of this study is to develop a new first production flaw detecting system, which detects flaw of large-scale circuit quickly. In this report, we mention to a basic concept of proposed system, and performed some preliminary experiments using developed measurement systems. Demanded performance for first production flaw detecting system was discussed. And the concept of basic style of detecting system and optical set-up was selected. A preliminary first production flaw detecting system with galvano-scanner and multi photodiode array was developed to confirm a detection of flaws and pattern profile. Some basically experiments have been conducted to check the performance of this system. An imitated flaw was scratched on the circuit patterns and the experimental results show the sclatched flaw has been detected by this equipment. The height detecting technique for this system was mentioned and preliminary experiment using developed system. By using laser trigonometry method, displacement of height information was detected sufficiently.

Keywords: on-demand repair, laser, wiring board, circuit, flaw, defect

1. INTRODUCTION

Recently, high-mix low-volume production [1][2] is already one of the mainstreams of manufacturing technology. Many kinds of different productions must be manufactured while short time-span, therefore, the efficient production which does not need re-manufacture caused by flaw of production is the most important. To improve yield rate, that means a ratio between the number of non-defective productions and the one of all productions, advancement of manufacturing technology is a fundamental and effective solution. On the other hand, on-demand repair technique, which means in-process repairing if some flaws are detected, becomes also reliable solution because the flaws are successfully repaired and all defective productions change to passing ones.

Manufacturing of touch panel display with large scale printed electronics board is a typical example of the high-mix low-volume production. Although epoxy boards are widely used for printed circuit boards (PCBs), nowadays, plastic thin films such as polyimide are selected as printable electronics substrate because of their flexibility. Such flexible substrates often cause flaws of printed wiring, specifically breaking, chipping and exfoliating from films. The flaws of excess (shorts of wirings) can be solved by laser abrasion technique [3][4], but the flaws of missing mentioned above, another repairing method is needed.

National Institute of Advanced Industrial Science and Technology (AIST) has proposed Laser assisted Ink-Jet printing (LIJ) technology [5] to solve missing of wiring. This method supplies silver nanoparticle ink to missing point of wiring by using ink-jet printer nozzle, and irradiating a laser light on the printed point to dry up ink droplets.

To establish in-process repairing system for touch panel display, a production flaw (braking, chipping and exfoliating) detecting system in high speed is demanded with combining to the LIJ technology. Figure 1 shows the schematic image of an actual on-demand repair system. Some images of circuit flaws are also showed in this Fig. There are three steps for on-demand repair system, those are, step 1: first production flaw detecting system detects certain area which is likely to be defective, step 2: camera system watches the area and obtains visual flaw image, step 3: repairing system with laser assisted ink-jet repairs the flaw. Obviously, the first production flaw detection is also key technology for on-demand repair because if we cannot detect actual flaws, we never repair circuit. Although the camera system is one of the most effective techniques for detecting flaws, this system needs long time to survey all of circuit board since the camera scope only covers several

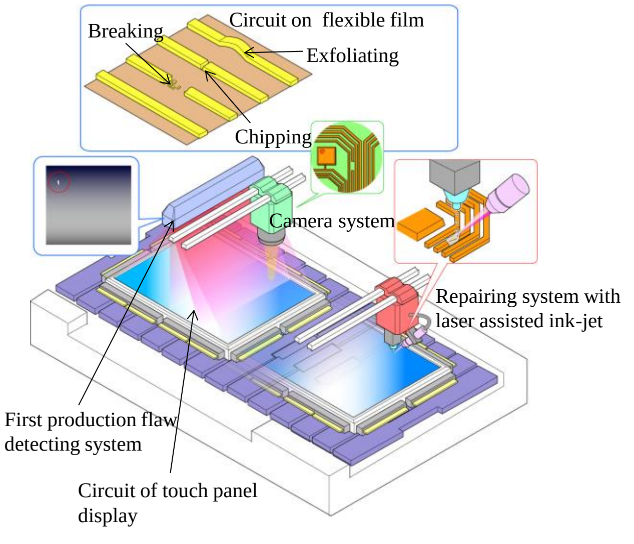

Fig. 1: Circuit flaws and schematic image of an actual on-demand repair system

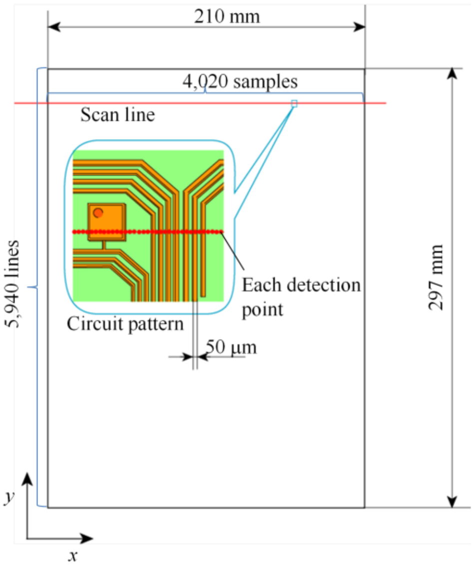

Fig. 2: Measurement for A4 size printed circuit

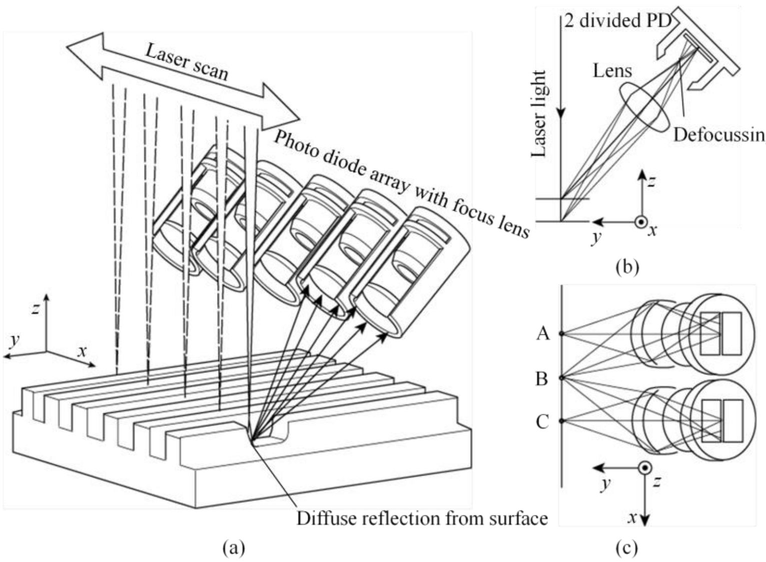

Fig. 3: Schematic diagram of first production flaw detecting system with profile measurement ability

square millimeters for detecting wires in several ten microns order. Then it is better to use the camera system after the first production flaw detecting system narrowing down the flaw area.

Therefore, the aim of this study is to develop a new first production flaw detecting system, which is intended to combine with LIJ system. Needed inspection abilities for detecting system were discussed from industrial demand. A series of photo-diode array and scanning laser set-up was proposed for detecting flaw, and optical system was examined. A preliminary first production flaw detecting system with galvano-scanner and multi photodiode units was developed to confirm a detection of flaws and profile. Some basically experiments have been conducted to check the performance of this system.

2. DESIGN FOR DETECTION SYSTEM

2.1 Needed inspection abilities for detection system

Typical takt-time of printable electronics using stencil mask and squeegee is about 15 seconds for A4 size. All on-demand repair time, which include flaw detection and repairing time, should be the almost same length as it. The repair time by the LIJ method is required for about 7 seconds. Time to detect is required not only before repair but after repair, in order to check the repair part by LIJ. At the after repair time, it is enough just to check the repaired point. Then when we suppose that we need 1 second for checking this point, 7 seconds are assigned for flaw detection with camera observation. Without camera observation time, actual remained time for flaw detection may be 4 seconds at most.

Recent line width of printable electronics is 50 microns. Therefore required resolution of flaw detection system is at least 50 microns or higher. When we measure A4 size printed circuit board within 50 microns resolution by one after another scanning for long direction (y-direction) after short direction (x-direction) as shown in Fig.2, 4,020 times samplings for x direction and 5,940 lines for y direction are required. Thus, measurement times for one line should be 673 microseconds and times for one position in x direction should be 167 nanoseconds.

For the first flaw detecting system, profile measurement ability for the depth of breaking or chipping, amount of exfoliation from base film should be also needed for product control. Within whole scanning line, demanded measurement accuracy is micron order and range is about several hundred microns.

2.2 Proposal for optical flaw detection system

Line scan CCD camera with 4,096 pixel and 80 kHz sampling speed [6] has enough efficiency to fulfil above needed abilities of resolution and speed. Using this line scan CCD with suitable optical lens and scanning stage for y-direction, the first production flaw detecting system will be realized.

But providing profile measurement ability, also mentioned above, is difficult for this set-up. Of course, scanning of laser displacement sensor can easily solve the profile measurement issue, but to sufficient first scanning speed is unattainable.

Thus, in this study, we propose the measurement system made from a series of photo-diode (PD) array and scanning laser set-up in Fig. 3 (a).

Laser beam scans the profile surface, and photo diode array detects diffuse reflection from the surface. By monitoring reflection output of each photo diode, the outputs differ clearly by whether the flaw exists or not. 2-divided photo diode of each PD array detects the height of profile by using laser trigonometry method as shown in Fig. 3 (b). Defocusing with z-direction change makes non-linearity of output. Because the laser beam moves x-direction, reflection point is changing with time as Fig. 3 (c). Then we have to select enough apertures of lens and PD, and prepare calibration relationship between the PD output and displacement at each x-point. In this figure, at A and C positions, we can get almost same output each other, but at B position, cooperating measurement between two PD should be needed since the reflection light spot focuses in the end of light receiving surfaces. In this report, first, we used single light receiving PD array to check the ability of flaw detection, and used only one divided PD to valuate measurement performance. Cooperating displacement measurement will be conducted in next step.

2.3 Design for optical layout

In order to indicate guidelines for optical system design, relationship between receiving angle of photo diode and reflection light quantity were investigated qualitatively.

Figure 4 shows experimental set-up. A laser diode irradiates a specimen perpendicularly. A photo diode is attached to rotary stage around the specimen, and it detects reflection light quantity at each receiving angle φ.

Figure 5 shows the experimental results. The measured specimens were plated Au circuit wiring, glass epoxy substrate, and black coated aluminum. The reflection of the Au wiring circuit was large at the angles less than approximately 40 degrees, and at other angles, the substrate had a higher reflection than the circuit. The reflection from black coated aluminum had a small reflection light quantity in the whole angle. Because the wiring circuit has a metal surface, it is thought that an ingredient of direct reflection is mainly distributed over the incidence angle neighborhood (< about 40 degrees). On the other hand, the substrate has almost ideal diffusion reflection surface, the reflection light quantity was still large at more than 40 degrees of the angle.

In the actual flaw detection system, reflection from wiring circuit part should be detected strongly. Therefore angle of inclinations for photodiodes was selected approximately 30 degrees from the incident direction of the laser.

Next, receivable area and focal distance of the flaw detection system were examined as shown in Fig. 6.

In this study, silicone photo diodes (Hamamatsu: S1226-8BK) were used. Light receiving area of this photo diode is 5.8 × 5.8 mm, but actual receivable length in x-direction was about 8 mm since diagonal direction was selected. Combining two convex lenses with f = 120 mm and two ones with f = 30 mm, we prepared spot image forming lens with f = 16.3 mm for photo diode array. In Fig. 6, imaginary combined lenses are shown. Because of mechanical dimension of case of PD array, the minimum distance between each PDs was restricted in 35 mm. Distance from measured surface to lens (principal point) was selected in 100 mm. To make the spot image forming with these combined lenses, distance from lens to light receiving surface of PD was selected in 19.5 mm. From Fig. 6, the area length B_2-B_1 = $2R$ is the receivable area and actual amount will be R = 20.5 mm. Therefore, 41 mm of receivable area for one photo diode can be achievable and cooperating displacement measurement by adjoined photodiodes should be realized. Of course, the aberration of the lens, denoted as B_1', affects the measurement accuracy, but our setup has not yet taken it into account.

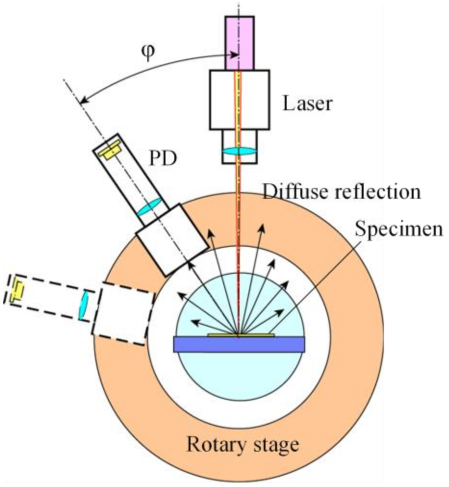

Fig. 4: Experimental set-up to detect reflection light quantity

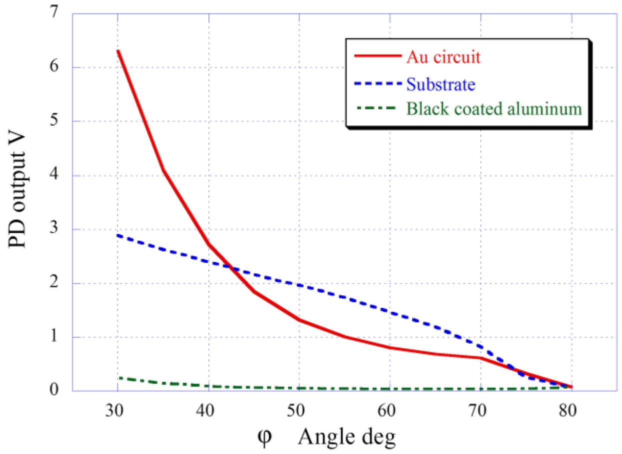

Fig. 5: Results of detecting reflection light quantity

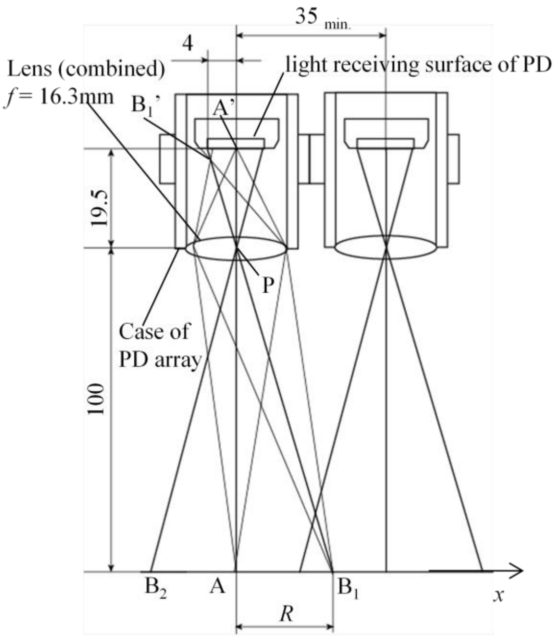

Fig. 6 Receivable area and focal distance of PD array

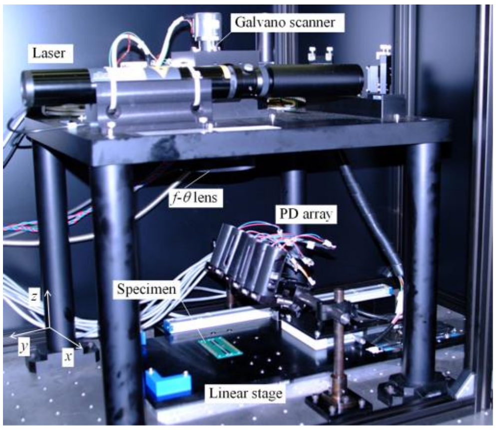

Fig. 7: Photograph of system set-up

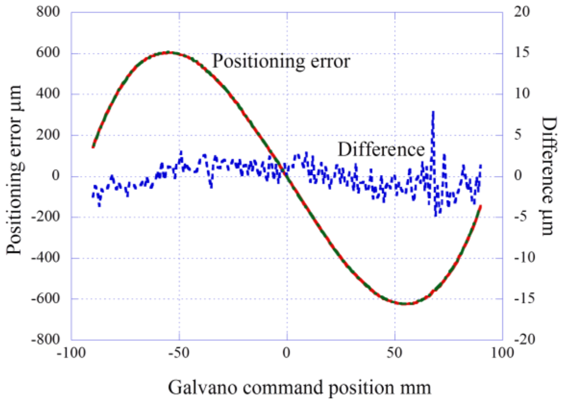

Fig. 8: Positioning accuracy of galvano-scanner

3. DETECTION SYSTEM AND EXPERIMENTAL RESULTS

3.1 System set-up

From the discussion mentioned above, a prototype of first production flaw detection system was developed as shown in Fig. 7.

A He-Ne laser (Melles griot: 05-LHP-111) is a light source of this system. Laser spot is focused on the specimen with 50 microns diameter by *f*-*θ* lens (*f* = 353.2 mm, diameter of lens = 110 mm). A galvano-scanner (Y-E data: galvano unit) scans a laser in the range of 200mm along *x*-axis at up to 3,000mm/s in speed. Actually this scan speed is still lower than needed inspection mentioned in section 2.1, since developed system is verification model for flaw detection. A measured specimen is set on the top of linear stage (Nikki denso: NVA-AM τ-linear servo motor) with 300 mm range for *y*-axis. A linear encoder (Magnescale: SR-77), which has minimum resolution 0.01 microns is attached for positioning.

6 photo diodes, those which have same optical layout as in section 2.3, are placed in line to detect the reflection light from the specimen.

3.2 Preliminary experiments

Before flaw detection experiment, some preliminary experiments have been tried.

For the first, positioning accuracy of galvano-scanner was checked to make a corresponding reliability with linear stage.

Since the scanner has same galvano-mirror with *x* and *y* axes, positioning accuracy of *y* direction for galvano-scanner and linear stage were compared. A quadrant photo diode (QPD) was attached on the linear stage, and galvano-scanner focused on central position of QPD. Then, the galvano-scanner moved to next certain position and the linear stage followed to the position where the light receiving surface divided into four of QPD output the same voltage. By comparing galvano and linear encoder position, the positioning accuracy was estimated.

The results are shown in Fig. 8. Range for ± 90 mm with 1 mm steps was compared. In this figure, two experimental results and differences of these results are shown. From these results, the maximum positioning error amounts about ± 600 microns. Although those errors make distortion of profile image, measured repeatability of these errors was within 15 microns. Moreover, the galvano-scanner has compensation matrix for positioning in controller. Therefore we can have confirmation for corresponding reliability with linear stage and galvano-scanner.

Next, the receivable area of the photo diode array was confirmed. An epoxy flat plate as specimen was set on the stage, and laser scanned on the specimen. All 6 photo diode detect the reflection light while laser scanning.

Figure 9 shows the results about photo diode output and average of all outputs. Each output looks like having a spike noise, but this signal comes from reflection of the epoxy plate as shown in Fig. 10. There are 5-times repeatable results of photo diode No.4 outputs and all of them are well corresponding, and it means that the outputs are caused by

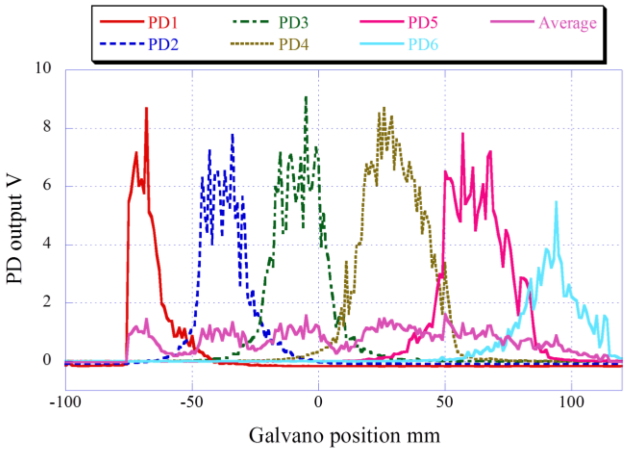

Fig. 9: Outputs of detecting reflection

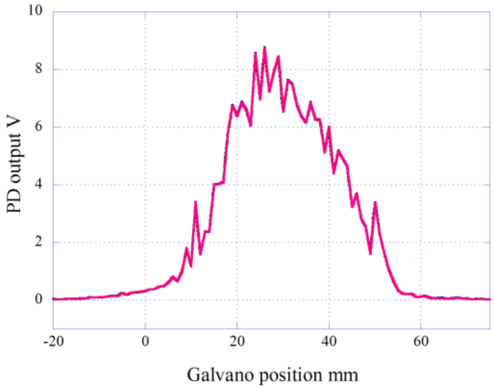

Fig. 10: 5-times repeatable results of PD 4

profile reflection.

From each photo diodes and averaged output in Fig. 9, we can see that receivable area of each PDs is overlapping mutually. Although the output at the area which especially overlapped PD1 and PD2 is still low, PD array can detect continuously the reflection light within the limits which laser scans. More cautious optical system design to avoid aberration is needed for realizing uniform reflection light detection.

3.3 Flaw detection experiment

Flaw detection experiment was conducted to check the performance of this system. Actual Au plated circuit with 250 microns width and 200 microns interval were measured by developed system. Substrate of this circuit was same one as used at Fig. 9 and 10. An imitated flaw was scratched on the circuit patterns. This flaw did not make breaking of circuit or exfoliating from substrate, but it should be thought as flawed circuit if this is an actual product.

Data of PDs were logged with pitch of 50 microns and after one line scan, the linear stage moved with 100 microns.

Figure 11 shows the actual circuit pattern with imitate flaw and measurement result. The measurement result denotes that the galvano-scanner position as scanned laser line, the linear stage position as *y*-axis, and averaged output of all photo diodes. Clearly the scratched flaw was detected successfully by changing of light reflection.

3.4 Basically experiment for height measurement

As mentioned in section 2.2, this system can also measure the height of profiles when we install the divided photo diode as PD array.

For basically experiment, one quadrant photo diode (QPD) was attached to PD array and displacement was measured by this system as already shown in Fig. 3(b). In order to measure the z direction by trigonometry method, upper and lower two parts of QPD were treated as same light receiving surface. While displacement measuring, galvano-scanner was fixed in certain position, and additional installed *z*-stage moved to the specimen to detect changing of divided PDs. Same experiments were conducted in another galvano positions.

Figure 12 shows the experimental results. 0 micron position in this figure means that almost same position-A of Fig. 3(c), and others are the results about different galvano position along *x*-axis.

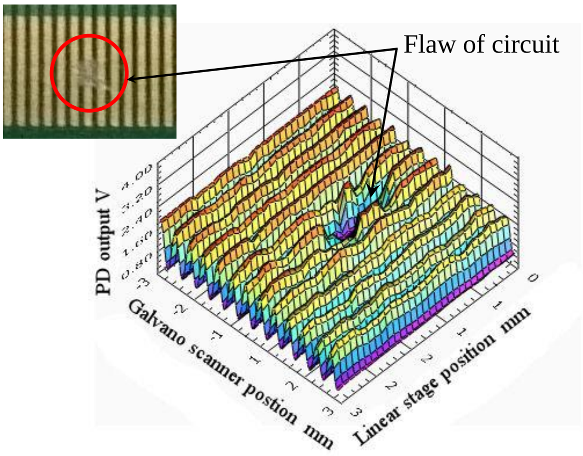

Fig. 11: Result of flaw detecting experiment

Because of narrow width of light receiving surface, experiments were only conducted within 300 micron range of galvano position, but all outputs show same results in spite of different position. Non-linearity at lower 200 microns part is thought that caused by the aberration of focus lens.

4. CONCLUSION AND FUTURE WORKS

A new first production flaw detecting system for on-demand repair is developed. For printed electronics, demanded performance for flaw detecting system was discussed. The concept of basic style of the system was proposed and optical layout was designed. A preliminary first production flaw detecting system with galvano-scanner and multi photodiode array was developed. Some basic experiments have been conducted. Imitated scratch on the actual circuit could be detected successfully. Displacement of height information was detected by using laser trigonometry method. More high speed response and reliable detection is demanded for developed system. Cooperating displacement measurement by mutual PD array will be conducted in next step. Installing divided photo diode for all PD array is also needed for providing profile measurement ability.

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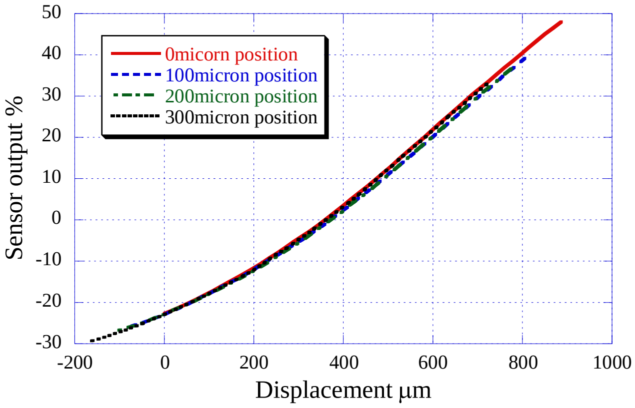

Fig. 12: Experimental results of displacement measurement